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FULL LENGTH ARTICLE

Study the flashover voltage for outdoor polymer insulators under desert climatic conditions

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KEYWORDS

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Flashover voltage;
Sandstorm effect;
Ultra violet (UV) radiation,
Surface roughness

Abstract This work presents a study of flashover voltage for outdoor polyester and composite insulators under some desert climatic conditions. Cylindrical polyester composite samples have been prepared after incorporated with different concentrations of inorganic fillers e.g., alumina tri-hydrate [ATH], boric acid [H_3BO_3] and magnesium hydroxide [$Mg(OH)_2$] to improve the electrical, mechanical and thermal properties in addition to maximize the surface flashover voltage and decrease the tracking phenomena.

Results showed that flashover voltage reaches to 38 kV for samples without filler and 47 kV for samples containing 50% of ATH filler in dry condition. A comparison between inorganic fillers under various environmental conditions showed higher flashover voltage values for samples containing ATH filler than that of samples containing H_3BO_3 and $Mg(OH)_2$ fillers at all filler concentrations. Flashover voltage increases 24% by adding ATH filler for polyester samples under sandstorm conditions. Also, in this study, the effects of sandstorm, ultra violet (UV) radiation, mechanical strength (compressive and tensile strengths) and thermal performance with respect to surface of the sample under test have been investigated in detail.

1. Introduction

High voltage outdoor insulators used in transmission lines and substation are being subjected to various operating conditions and environments. Contamination on the surface of insulators enhances the leakage current that develops which may lead to flashover and power system outage and it is the essential element in power system outages with contaminated insulators on the systems which are located in desert sites and manufacturing cities [1–3].

However, since early sixties, alternative materials namely polymers have emerged and presently are being used extensively for a variety of outdoor insulator applications. Polymeric materials used for outdoor insulation have been referred to various names such as composite, non-ceramic, plastic and synthetic insulation [4–6].

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Polymers have been preferred over porcelain and glass by many utilities for the housing of high voltage outdoor materials. Polymer has many benefits over ceramic such as; cheap, light weight, easy handling and installation, shorter manufacturing time, high impact resistance, high mechanical strength, greater flexibility in product design, reduced breakage (non brittle characteristic) and resistance to vandalism.

These advantages have driven the utility people to prefer polymer insulators over conventional porcelain or glass insulators. The polymeric materials, particularly silicon rubber, epoxy, ethylene propylene diene monomer (EPDM) and polyesters are used as insulators for transmission, distribution, termination of underground cables, bushings and surge arrester housings [7–10].

High voltage transmission lines are often subjected to the deposition of contaminated substances, high temperature, humidity and sandstorm. In the desert, sandstorm – that has particles – increases the surface roughness of composite polymer insulators. The high degree of UV radiation can cause physical as well as chemical changes on the surface of composite insulators [11–17].

Cylindrical rod specimens chemically prepared from polyester have been tested to examine the effect of desert weather such as, sandstorm and ultra violet on the flashover voltage performance of composites. The ac (50 Hz) flashover voltage of polyester specimens has been investigated in this study, three types of fillers such as; alumina trihydrate (ATH) [$Al(OH)_3$], boric acid [H_3BO_3] and magnesium hydroxide[$Mg(OH)_2$] are in use for increasing the electrical performance of polyester specimens [18–20].

2. Experimental set-up and techniques

2.1. Material specimen

Specimens have been prepared from unsaturated polyester resin [2121P-1], having the following physical properties; appearance: faint blue-transparency, Styrene monomer content: 36–39%, viscosity-Brookfield at 25 °C: 300–400 and specific gravity at 25 °C: 1.11. Polyester specimens were fabricated as cylindrical rods having 10 mm diameter and 100 mm length. Powder inorganic fillers with particle size ranging from 61–74 μm have been added to polyester. Three types of fillers have been used, namely ATH, H_3BO_3 and $Mg(OH)_2$ with different concentrations, the composition of the specimens is given in Table 1.

2.2. Test apparatus

2.2.1. Electrical test supply and electrodes

The ac (50 Hz) high voltage was obtained from a single-phase high voltage transformer (150KV–15KVA). The electrodes were made of copper with 5 mm thickness and 10 mm diameter. The electrodes were fixed to the specimens, one at the top and the other at the bottom.

2.2.2. Artificial sandstorm apparatus

To simulate the effect of the artificial sandstorm on the surface of composite H.V insulators, specimens had been exposed to continuous artificial sandstorm by using the device (Abrasive blast cabinet for sandstorm simulation –Model 38246). The sand grain size is selected to be less than 250 microns to simulate the grain sand of natural sandstorm. Cabinet operates under different pressures supplied from a variable air compressor up to six bars. The blast system is a venture type, through the design of gun system. Cabinet has a glass window to facilitate the observation of specimen's surface inside the device. The surfaces of composite specimens were exposed to three different time intervals (5, 10 and 15 min.) with artificial sandstorm, surface roughness had been measured for all specimens before and after each exposure to sandstorm by using an optical interference microscope.

2.2.3. Ultra violet radiation apparatus

Ultraviolet (UV) light is one of the major factors responsible for degradation of polymeric insulators. ***Main source of UV rays is Sun, corona formation and dry band arcing activities on insulation surface. Simulate the UV light and observe the local discharge phenomenon on the composite surface, all test specimens had been exposed to UV radiation from different locations by using UV lamps. Three various times of UV radiation exposures have been recorded (720, 1440 and 2160 h.) according to ASTM D 7238, the surfaces of all specimens have been monitored during UV exposure.

2.2.4. Mechanical test

The effect of inorganic fillers such as; ATH, H_3BO_3 and $Mg(OH)_2$ on the mechanical performance of polyester and composites has been examined during this work. Mechanical tests such as compressive and tensile strengths have been done to evaluate the mechanical performance of composite insulators according to ASTM D695 and ASTM D638 for compressive and tensile strengths respectively, all specimens have been tested.

2.2.5. Thermal stability test

A thermal test such as thermogravimetric analysis (TGA) was performed to measure the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. Measurements are used primarily to determine the composition of materials and to predict their thermal stability at temperature up to 750 °C. The technique can characterize materials that exhibit weight loss or gain due to decomposition, oxidation or dehydration.

Table 1 Composition of specimens with different types and filler concentrations.

Concentration of filler by weight (wt.%)	Types of fillers		
	$Al(OH)_3$	H_3BO_3	Mg $(OH)_2$
20	–	B_{20}	Mg_{20}
30	ATH_{30}	B_{30}	Mg_{30}
40	ATH_{40}	B_{40}	Mg_{40}
50	ATH_{50}	–	–

3. Results and discussion

3.1. Surface roughness measurements

Surface roughness values for all samples before exposure to sandstorm effects are given in Table 2.

It can be observed that, the surface roughness is almost the same value which equals around (0.89–0.90) μm for polyester and composite specimens with various concentrations of ATH, H_3BO_3, and $Mg(OH)_2$ fillers. While, surface roughness values for all samples after exposure to sandstorm effects are given in Table 3.

After exposure of all specimens to artificial sandstorm for 5 min., surface roughness (μm) was increased with different values according to the type of filler and its concentration.

Increasing some of the filler concentrations (wt.%) lead to reducing surface roughness (μm) for composite insulators. For example, polyester (blank) specimen has a surface roughness of 4.65 μm, while adding ATH filler with different concentrations (30, 40 and 50 wt.%) to polyester. Surface roughness values are 2.55, 2.31 and 2.11 μm the same trend can be seen for H_3BO_3 surface roughness respectively.

Whereas, adding 20, 30 and 40 wt.% of $Mg(OH)_3$ filler leads to increasing surface roughness values (5.03, 5.71 and 6.02 μm) respectively to be higher than unfilled polyester composite.

Among the three fillers taken in this study, the inclusion of magnesium hydroxide causes a maximum increase in the surface roughness compared with unfilled polyester specimens.

With an exposure time of 10 min. to sandstorm, the surface roughness is increased for all polyester and composite specimens. While, with an exposure time of 15 min. to sandstorm, the surface roughness value increases more than its value in the 10 min. For example, at 50 wt.% of ATH the surface roughness is 2.11, 3.98 and 5.83 μm at 5, 10 and 15 min. respectively.

3.2. Flashover voltage of composite insulators under different conditions

Flashover voltages have been recorded for composite insulators under dry/virgin, sandstorm and UV radiation conditions.

Table 2 Surface roughness values for all virgin specimens.

Specimens	Surfaces roughness (R_{max} μm)
Blank (polyester)	0.90
Polyester + $ATH_{30,\ 40\ \mathrm{and}\ 50}$	0.89
Polyester + $B_{20,\ 30\ \mathrm{and}\ 40}$	0.89
Polyester + $Mg_{20,\ 30\ \mathrm{and}\ 40}$	0.90

3.2.1. Flashover voltage of virgin specimens

Effect of flashover voltage of polyester specimens with different concentrations [20, 30, 40 and 50 wt.%] of fillers [ATH, H_3BO_3 and $Mg(OH)_2$] at dry weather is shown in Fig. 1.

It can be seen from Fig. 1 that, flashover voltage is equal to 38 kV for polyester sample without any filler, while composite samples ATH_{30} (polyester + 30 wt.% ATH), ATH_{40} (polyester + 40 wt.% ATH) and ATH_{50} (polyester + 50 wt.% ATH) increase the flashover voltage to (41, 44 and 47) kV respectively. But for the composite samples B_{20}, B_{30} and B_{40} with added 20, 30 and 40 wt.% of H_3BO_3 filler which have lower values of flashover voltage recorded at 39, 40 and 42 kV respectively. However, this trend is not found in Mg_{20}, Mg_{30} and Mg_{40}, where the flashover voltage values drop to (37, 34 and 31) kV with the addition of 20, 30 and 40 wt.% of $Mg(OH)_2$ filler respectively.

Among the three fillers taken in this study, the inclusion of $Mg(OH)_2$ causes a maximum reduction in flashover voltage.

It can be noticed that, the flashover value of unfilled polyester specimens reaches to 38 kV whereas, ATH filler increases the electrical performance of polyester by almost 27% and H_3BO_3 filler increases it by almost 10.5% while $Mg(OH)_3$ filler decreases the electrical performance by almost 18.4%.

3.2.2. Effect of sandstorm on flashover voltage of composite specimens with different fillers

Simulate the effect of sandstorm on the surface of composite insulators; the surfaces of composite specimens were exposed to three different time intervals (5, 10 and 15 min.) with artificial sandstorm. A comparison between three different types of fillers such as ATH, H_3BO_3 and $Mg(OH)_2$ has been done to measure the ability of each filler to withstand sandstorm and keep surface roughness (μm) with low value.

3.2.2.1. ATH filler effect. Effect of ATH filler with different concentrations (30, 40 and 50 wt.%) on the electrical performance of composite insulators under exposure to sandstorm is shown in Fig. 2.

The above figure shows the relationship between the surface roughness of composite insulation (μm) with ATH filler at 0, 30, 40 and 50 wt.% of filler percentage and flashover voltage (kV).

Table 3 Surface roughness values for all samples after exposure to sandstorm effects.

Exposure time for sandstorm (min)	Fillers by weight (wt.%)	Surface roughness(R_{max} μm)	Fillers by weight (wt.%)	Surface roughness (R_{max} μm)	Fillers by weight (wt.%)	Surface roughness (R_{max} μm)
5	Blank	4.65				
	ATH_{30}	2.55	B_{20}	3.02	Mg_{20}	5.03
	ATH_{40}	2.31	B_{30}	2.85	Mg_{30}	5.71
	ATH_{50}	2.11	B_{40}	2.54	Mg_{40}	6.02
10	Blank	8.70				
	ATH_{30}	4.30	B_{20}	5.01	Mg_{20}	8.73
	ATH_{40}	4.08	B_{30}	4.73	Mg_{30}	9.34
	ATH_{50}	3.98	B_{40}	4.41	Mg_{40}	10.01
15	Blank	11.01				
	ATH_{30}	6.51	B_{20}	7.03	Mg_{20}	12.33
	ATH_{40}	6.02	B_{30}	6.72	Mg_{30}	13.25
	ATH_{50}	5.83	B_{40}	6.32	Mg_{40}	14.39

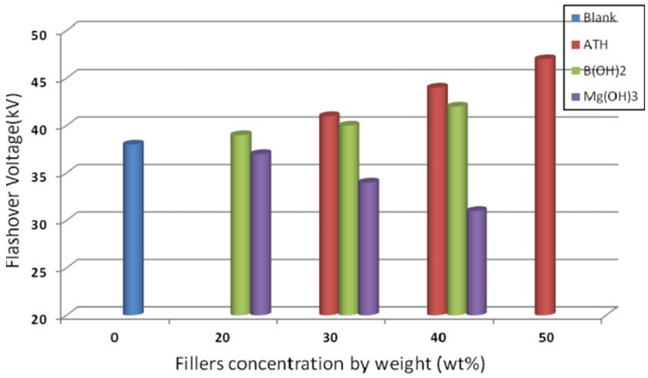

Figure 1 Illustrates the flashover voltage (kV) at dry condition for polyester and composite specimens.

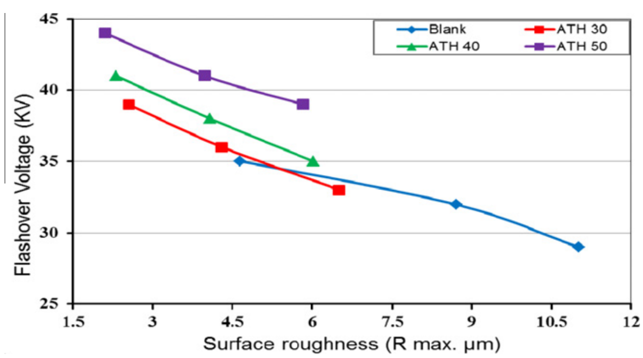

Figure 2 Flashover voltage (kV) against surface roughness (μm) of composite insulators with various ATH filler percentage.

It can be observed from the figure that, the flashover voltage decreased by increasing the surface roughness (μm) with 0, 30, 40 and 50 wt.% of ATH filler as follows:

- At [ATH_{30}] composite specimens (polyester + 30 wt.% ATH), the flashover voltages are (39, 36 and 33) kV for surface roughness of (2.55, 4.3 and 6.51) μm respectively, under different sandstorm conditions.
- At [ATH_{40}] composite specimens (polyester + 40 wt.% ATH), the flashover voltages are (47, 36 and 35) kV for surface roughness of (2.31, 4.08 and 6.02) μm respectively, under different sandstorm conditions.
- At [ATH_{50}] composite specimens (polyester + 50 wt.% ATH), the flashover voltages are (44, 41 and 39) kV for surface roughness of (2.11, 3.98 and 5.83) μm respectively, under different sandstorm conditions.

The percentage reduction of flashover voltage for ATH_{50}, ATH_{40} and ATH_{30} for 15 min. exposure time to sandstorm is almost 17%, 20% and 19.5% respectively, compared to unfilled polyester specimens in the virgin condition.

3.2.2.2. H_3BO_3 filler effect. Effect of H_3BO_3 filler with different concentrations (20, 30 and 40 wt.%) on the electrical performance of composite insulators under exposure to sandstorm is shown in Fig. 3.

The above graphs show the relationship between the surface roughness (μm) of polyester sample with H_3BO_3 filler at

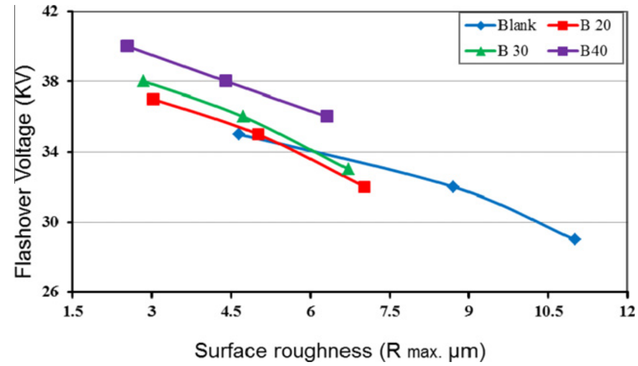

Figure 3 Flashover voltage (kV) vs. surface roughness (μm) of composite insulators with various H_3BO_3 filler percentage.

0, 20, 30 and 40 wt.% of filler percentage and flashover voltage (kV).

It can be seen that unfilled polyester specimens have lower flashover voltage value than of samples containing H_3BO_3 fillers at all filler concentrations under different surface roughness as follows:

- The unfilled polyester composite has a flashover voltage of (35, 32 and 29) kV at surface roughness of (4.65, 8.70 and 11.01) μm, the flashover voltage increases to (37, 35 and 32) kV and surface roughness values decrease to (3.02, 5.01 and 7.03) μm with the addition of 20 wt.% of H_3BO_3 filler when exposed to sandstorms for different times (5, 10 and 15 min).
- The unfilled polyester composite has a flashover voltage of (35,32 and 29) kV at surface roughness of (4.65, 8.70 and 11.01) μm, the flashover voltage increases to (38, 36 and 33) kV and surface roughness values decrease to (2.85, 4.73 and 6.72) μm with the addition of 30 wt.% of H_3BO_3 filler when exposed to sandstorms for different times (5, 10 and 15 min).
- The unfilled polyester composite has a flashover voltage of (35, 32 and 29) kV at surface roughness of (4.65, 8.70 and 11.01) μm, the flashover voltage increases to (40, 38 and 36) kV and surface roughness values decrease to (2.54, 4.41 and 6.32) μm with the addition of 40 wt.% of H_3BO_3 filler when exposed to sandstorms for different times (5, 10 and 15 min).
- [H_3BO_3]$_{40}$ filler improve the flashover voltage of unfilled polyester specimens with average value around 15% under different conditions of sandstorm.
- An improvement in the flashover voltage value for polyester specimens loaded with 40 wt.% filler has been achieved compared with polyester specimens loaded with 30 wt.% and 20 wt.% of H_3BO_3 fillers by 8% and 11% respectively when exposed to sandstorms for 15 min.

3.2.2.3. $Mg(OH)_2$ filler effect. Effect of $Mg(OH)_2$ filler with different concentrations (20, 30 and 40 wt.%) on the electrical performance of composite insulators under exposure to sandstorm is shown in Fig. 4.

These graphs show the relationship between the surface roughness (μm) of polyester specimens with $Mg(OH)_2$ filler at 0, 20, 30 and 40 wt.% of filler percentage and flashover voltage (kV) and it can monitor the following:

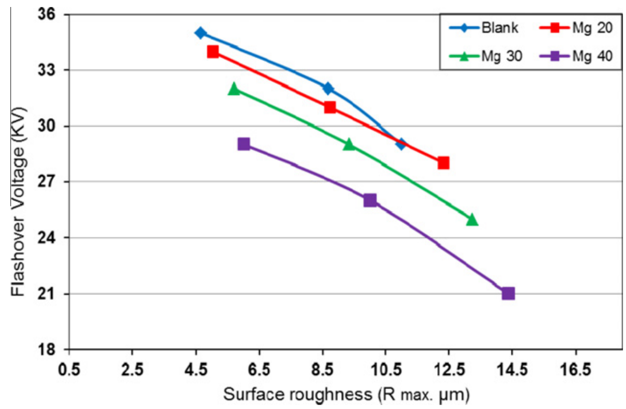

Figure 4 Flashover voltage (kV) versus surface roughness (µm) of composite insulators with various $Mg(OH)_2$ filler percentage.

- The unfilled polyester specimens have higher flashover voltage value than its value of samples containing $Mg(OH)_2$ fillers at all filler concentrations under different surface roughness.
- It is interesting to note that composite samples Mg_{20} (polyester + 20 wt.% $Mg(OH)_2$), Mg_{30} (polyester + 30 wt.% $Mg(OH)_2$)and Mg_{40} (polyester + 40 wt.% $Mg(OH)_2$) increase surface roughness compared with unfilled polyester sample from (4.65, 8.70 and 11.01) µm to (5.03, 8.73 and 12.33), (5.71, 9.34 and 13.25) and (6.02, 10.01 and 13.25) µm respectively. While a decrease in flashover voltage compared with unfilled polyester sample from (35, 32 and 29) kV to (34, 31and 28) kV, (32, 29 and 25) kV and (29, 26 and 21) kV respectively at different sandstorm conditions.
- Lack of improvement in flashover voltage value for polyester sample loaded with 40 wt.% has been achieved compared with polyester sample loaded with 30% and 20% of $Mg(OH)_2$ filler.
- Flashover voltage of polyester composite is decreased by 25% when $Mg(OH)_2$ filler concentration increases from 20% to 40% when exposed to sandstorms for 15 min.

3.2.3. *Effect of UV on flashover voltage of composite specimens with different fillers*

Simulate the UV effect and observe the local discharge phenomenon on the surface of the polyester specimens, all test specimens have been subjected to UV radiation from different locations by using UV lamp. A comparison between three different types of fillers e.g., ATH, H_3BO_3 and $Mg(OH)_2$ has been done through three various times to measure the ability of each filler to withstand UV rays.

3.2.3.1. ATH filler effect. Study of the effect of ATH filler with different concentrations (30, 40 and 50 wt.%) on the electrical performance of composite insulators after exposure to different times of UV radiation (0, 720, 1440 and 2160 h.) is shown in Fig. 5.

The test results for UV radiation and direct effect on flashover voltage are shown in Fig. 5, it is seen as follows:

- In all the specimens irrespective of the filler material, the flashover voltage of the composite insulators decreases with the increase of the exposure time for UV rays compared with flashover voltage values in virgin conditions.
- The unfilled polyester composite has flashover voltage of (36, 34 and 32) kV during exposure to UV rays (720, 1440 and 2160 h.) respectively.
- It may be seen from Fig. 5 that flashover voltage value increased with the addition of 30, 40 and 50 wt.% of ATH filler respectively.
- Flashover voltage of polyester composites increases by 14.5% when the percentage of ATH filler increases from 30 to 50 wt.% at 2160 h. of exposure time for UV rays.
- Thus from the present analysis, it is clear that ATH_{50} (polyester + 50%wt of ATH) is the most effective filler percentage to improve flashover voltage characteristics of polyester composites.

3.2.3.2. H_3BO_3 filler effect. Study of the effect of H_3BO_3 filler with different concentrations (20, 30 and 40 wt.%) on the electrical performance of composite insulators after exposure to different times of UV radiation (0, 720, 1440 and 2160 h.) is shown in Fig. 6.

It is evident from Fig. 6 that flashover voltage (kV) of all polyester specimens with different concentration of fillers decreases with increasing the time exposed to UV rays as follows:

- At 720 h the unfilled polyester composite has a flashover voltage of 36 kV, this value increases to (38, 39 and 41) kV with the addition of (20, 30 and 40) wt.% of H_3BO_3 filler respectively.

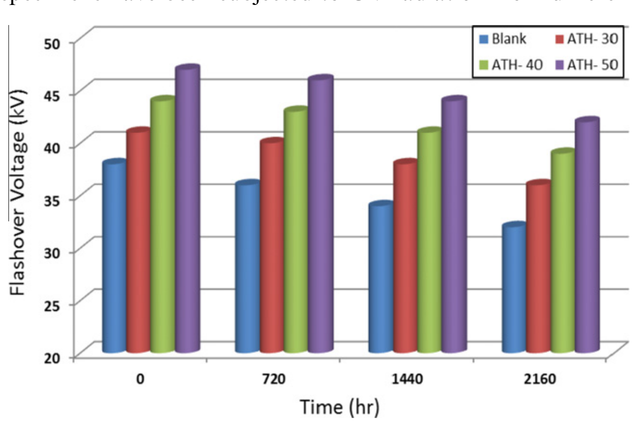

Figure 5 Flashover voltage (kV) against exposure time (h) to UV radiation of composite insulators with a range of ATH filler percentage.

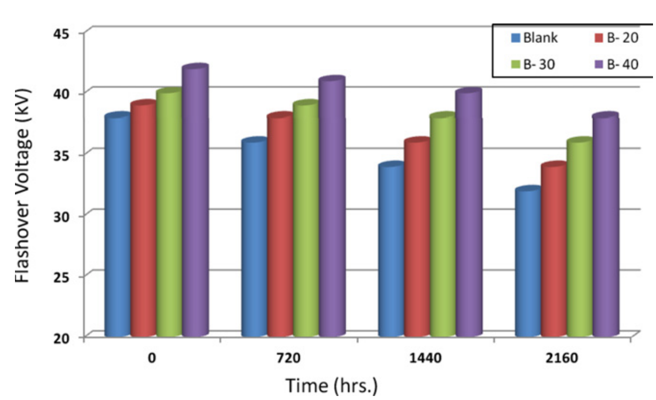

Figure 6 Flashover voltage (kV) versus exposure time (h) of UV radiation for composite insulators with a variety of H_3BO_3 filler percentage.

- At 1440 h the unfilled polyester composite has a flashover voltage of 34 kV, this value increases to (36, 38 and 40) kV with the addition of (20, 30 and 40) wt.% of H_3BO_3 filler respectively.
- At 2160 h the unfilled polyester composite has a flashover voltage of 32 kV, this value increases to (34, 36 and 38) kV with the addition of (20, 30 and 40) wt.% of H_3BO_3 filler respectively.
- Flashover voltage of polyester composites increases by 12.5% when the percentage of H_3BO_3 filler increases from 20 to 40 wt.% at 2160 h. of exposure time for UV rays.
- $[H_3BO_3]_{40}$ filler improves the flashover voltage of unfilled polyester specimens with average around 14.5% under different UV radiations.

3.2.3.3. Mg $(OH)_2$ filler effect. Study of the effect of $Mg(OH)_2$ filler with different concentrations (20, 30 and 40 wt.%) on the electrical performance of composite insulators under exposure to UV radiation (0, 720, 1440 and 2160 h.) is shown in Fig. 7.

It is clear from Fig. 7, the relation between flashover voltage and exposure time of UV rays for polyester specimens with different concentrations of $Mg(OH)_2$ filler as the following:

- In all the specimens, increasing the percentage of $Mg(OH)_2$ filler decreases the flashover voltage of polyester composite under UV conditions.
- The unfilled polyester composite has a higher flashover voltage value than its value of samples containing $Mg(OH)_2$ filler at all filler concentrations (20, 30 and 40 wt.%) under different periods of ultra violet radiations.
- At (720, 1440 and 2160) h, the unfilled polyester composite has flashover voltages of (36, 34 and 32) kV respectively, these values drop to (35, 32 and 30) kV, (33, 30 and 27) kV and (30, 28 and 24) kV with the addition of (20, 30 and 40) wt.% of $Mg(OH)_2$ filler respectively.
- Among the three fillers taken in this study, the inclusion of $Mg(OH)_2$ causes maximum reduction in the flashover voltage.
- Lack of improvement in the flashover voltage value for polyester sample loaded with 40 wt.% has been achieved compared with polyester sample loaded with 30 wt.% and 20 wt.% of $Mg(OH)_2$ fillers which is 11% and 25% respectively when exposed to UV rays for 2160 h.

3.3. Mechanical test

3.3.1. Compressive and tensile strength measurements

The mechanical properties of polymeric insulators are of considerable importance to users and manufacturers. Virgin specimens have been tested for compressive and tensile strengths. The calculation of compressive strength is given by dividing the maximum compressive load carried by the specimen during the test by the original minimum cross section area of specimen. While the calculation of tensile strength is given by dividing the maximum load by the average original cross-sectional area in the gage length segment of the specimen. Express the result in kg/cm^2 according to ASTM D695 and ASTM D 638.

Figures 8 and 9 show the obtained experimental results of compressive and tensile strengths for virgin specimens.

It is apparent from Figures 8 and 9 that compressive and tensile strengths (kg/cm^2) of all polyester specimens with different concentration of fillers decrease with increasing filler percentage as follows:

- In all the virgin specimens irrespective of the filler material, the compressive and tensile strengths (kg/cm^2) of the composite samples decrease with the increase of filler percentage (wt.%).
- The compressive and tensile strength (kg/cm^2) values of ATH composite samples are higher than samples of H_3BO_3 and $Mg(OH)_2$ fillers.
- The unfilled polyester composite has a compressive strength value of 1785 kg/cm^2 and it may be seen from Figs. 8 and 9 that this value slightly decreases to (1695, 1508 and 1248) kg/cm^2 with the addition of (30, 40 and 50) wt.% of ATH fillers respectively.

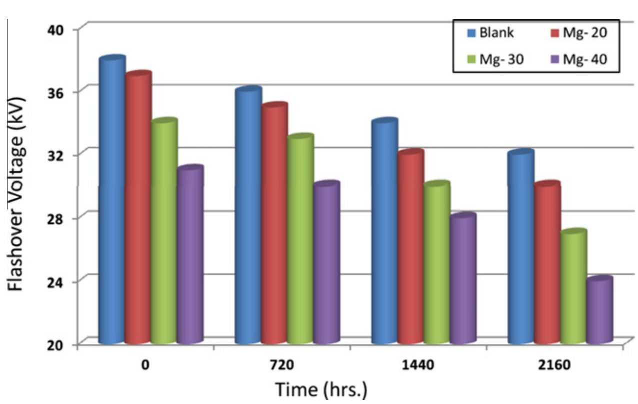

Figure 7 Flashover voltage (kV) vs. exposure time(h) of UV radiation for composite insulators with the addition of $Mg(OH)_2$ filler percentage.

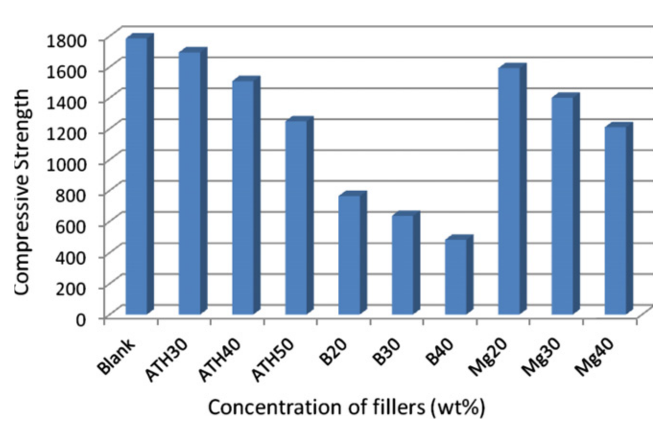

Figure 8 Compressive strength (kg/cm^2) of virgin specimens against different types and concentrations of fillers.

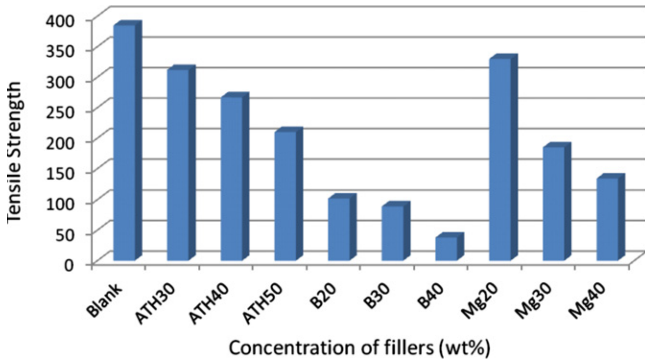

Figure 9 Tensile strength (kg/cm^2) of virgin specimens against different types and concentrations of fillers.

- But the drop in values of compressive strength is (1592,1401 and 1210) kg/cm^2 with the addition of (20, 30 and 40) wt.% of $Mg(OH)_2$ filler and (764, 636 and 484) kg/cm^2 with the addition of (20, 30 and 40) wt.% of H_3BO_3 filler respectively.
- The tensile strength value (385 kg/cm^2) of polyester without filler is higher than that of composites types of fillers, while the tensile strength values of composites with ATH filler are higher than composites of both H_3BO_3 and $Mg(OH)_2$ fillers.
- Rate of decrease in the results of compressive strength is different from one filler to another. For example, ATH filler gives 1695 kg/cm^2 at the lowest filler concentration and 1248 kg/cm^2 at the highest concentration, which means that the rate of decrease is almost 26%, while the rate for $Mg(OH)_2$ is 23% and the rate for H_3BO_3 is 37%
- Rate of decrease in the results of tensile strength is different from one filler to another. For example, ATH filler gives 210 kg/cm^2 at the lowest filler concentration and 312 kg/cm^2 at the highest concentration, which means that the rate of decrease is almost 32%, while the rate for H_3BO_3 is 63% and the rate for $Mg(OH)_2$ is 59%

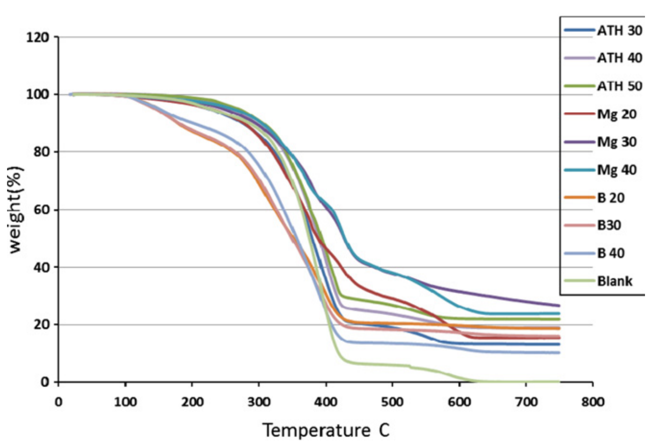

Figure 10 TGA curves for polyester with different types and concentrations of filler.

- The reduction percentage of compressive and tensile strengths for ATH_{50}, ATH_{40} and ATH_{30} is almost 30%,15% and 5% for compressive strength and 18%,30% and 45% for tensile strength respectively, compared to unfilled polyester specimens.

3.4. Thermal stability of composite insulators

3.4.1. Thermogravimetric analysis test (TGA)

Thermogravimetric analysis (TGA) of polyester and its composites was investigated on finely powdered samples as shown in Fig. 10.

Thermogravimetric analysis (TGA) can measure the moisture content, thermal cleavage, thermal degradation temperature and thermal stability of composite material. TGA measurements of polyester and composites revealed the thermal stability and thermal degradation of the tested specimens.

The TGA of polyester composites is shown in Fig. 10; it is observed from the figure that, varying either the type or concentration of filler influences the thermal stability and degradation behavior of polyester and composite. Weight loss of ATH specimens was smaller than the polyester at different concentrations when temperature was increased in the range from 30 to 250 °C.

Weight loss of ATH50 specimen was smaller than ATH40 and ATH30 specimens when temperature was increased in the range from 250 to 750 °C, the same trend can be obtained for specimens of polyester with H_3BO_3 and Mg(OH)2 with various concentrations.

It can be concluded that, the filler content has an effect on the beginning of decomposition. Comparison between fillers indicates that, specimens with ATH with different concentrations result in a retarded weight loss rate within a high temperature region. TGA test illustrates that polyester loaded with ATH represents the best polyester composites from a thermal stability point.

4. Conclusion

This paper has focused on the effect of desert climate on the electrical, mechanical and thermal performance of composite polymer insulators. The findings can be summarized as follows:

- The type and percentage of filler have pronounced effects on the electrical, mechanical and thermal performance of polyester composite insulators.
- There is a critical percentage of filler, which can be added with respect to the quantity of polyester, and the suitable percentage is 50% of ATH filler.
- Adding inorganic fillers such as ATH and H_3BO_3 decreases the surface roughness of samples and increases the flashover voltage under the sandstorm effect .While, $Mg(OH)_2$ filler increases the surface roughness of samples and decreases the flashover voltage under the same condition.
- The unfilled polyester composite has a lower flashover voltage value than of samples containing ATH and H_3BO_3 fillers and higher than samples containing $Mg(OH)_2$ filler at all filler concentrations under UV radiations at different exposure times.

- Among the three fillers taken in this study, the inclusion of $Mg(OH)_2$ causes a maximum reduction in the flashover voltage.
- The mechanical properties of polyester composites loaded with ATH are better than other samples loaded with H_3BO_3 and $Mg(OH)_2$.
- Polyester with ATH composites has good thermal stability and fire retardant properties.

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